ACID PRECIPITATION: THE CONTROVERSY[1]

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ABSTRACT.—Acid precipitation, caused by the long-range transport of pollutants, is a problem distinct from typical air pollution injuries. It has been implicated in several ill-defined growth declines in European and North American forests. The acid precipitation controversy is that we lack overwhelming scientific evidence that precipitation has been made more acidic than "normal" or that forests, lakes and streams have been harmed. Potential effects on forests include direct damage to leaf surfaces and reproductive organs, or indirect damage to other organisms or soil. Evidence of such effects from European forests may not be applicable to North America because of different species, past stand management, and heavier pollutant loadings in European forests. Examination of the "best" evidence in North America for decline due to acidic deposition — red spruce in high-elevation stands — does not provide compelling evidence that a significant effect is occurring.

INTRODUCTION

Air pollution damage to forests close to point sources such as smelters and power plants comes primarily from sulfur oxides and ozone, which cause direct damage to plant tissue. Acid rain, however, is caused by the long-range transport of air pollutants, especially sulfur and nitrogen oxides. These compounds acidify rain and other forms of precipitation, and are thought to damage forests, lakes and rivers, and soils because of their low pH and the acidifying nature of their constituents. This is distinct from what typically is called air pollution damage.

The technically correct term is acidic deposition, because the acidic material comes down not only in rain but also in snowfall, mists, and even as dry material deposited on leaf surfaces. Acidic deposition has been implicated in a series of ill-defined growth declines of forest trees in Europe and North America. These effects were reported in Scandinavia beginning in the 1960s, and in the U.S. and Canada in the 1970s.

The purposes of this paper are to introduce the acidic deposition phenomenon; describe some of the potential effects it may have on forest ecosystems, and the presumed linkage between acidic deposition and forest declines; and to examine the suspected acidic deposition damage to red spruce in the northeastern U.S.

SOURCES

Acidic deposition is caused by elevated levels of acidic precursors in the atmosphere resulting from human activities. While oxides of sulfur and nitrogen have received the most attention, volatile organic compounds also have been implicated. These precursors are transformed in the atmosphere to the mineral acids sulfuric acid and nitric acid. Also involved in the acidification process are ozone, hydrogen peroxide, and organic free radicals. These latter compounds are air pollutants in their own right, and it is necessary to separate out their harmful effects on forests from the pH effect of acidic deposition.

Data are lacking on amounts of acidic deposition since the turn of the century, but we do know how much of the precursors have been emitted into the atmosphere. Emissions of sulfates, nitrates, and volatile organic carbons have increased this century, as a result of industrialization and the automobile (NAPAP 1987). Sulfate emissions increased from nine million metric tons in 1900 to over 21 million metric tons in the late 1920s. Emissions dropped during the Depression, but increased

[1]A paper presented at the SAF National Convention (Technical Session) at Rochester, NY, October 16-19, 1988.

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after World War II. During the 1960s, use of coal to generate power decreased in the face of cheap oil, and so did sulfate emissions. They rose again in the 1970s, but lately have decreased because of efforts to control air pollution and in response to economic forces that caused massive restructuring of the U.S. industrial base (Gschwandtner et al. 1985).

The sources of sulfur emissions are mostly stationary energy-generating plants run by electric utilities or by industry. The sulfate emitted comes mostly from burning coal (MacDonald 1985).

Emissions of nitrous oxide and manmade volatile organic compounds have risen steadily since 1900, but have peaked in recent years. This comes despite an increase in the number of cars in the last decade or so (Gschwandtner et al. 1985; NAPAP 1987).

The sources of nitrogen oxide emissions are more diffuse, both in terms of types of generator and their geographic spread. The main sources are electric utilities and highway vehicles — that is, cars and trucks. There is some uncertainty whether high stack emitters like utilities are more important than ground-level emitters like cars.

On a regional basis, the most acidic rain in the U.S. falls on the Allegheny Plateau region of western Pennsylvania and New York; eastern Ohio; and northern West Virginia. Average rainfall pH in the entire Northeast is acidic. Significant differences from this regional average picture can occur at high elevations where fog and clouds are significant. Mountain clouds along the Appalachians, for example, are on average pH 3.6, compared to 4.2 for rain. An acid cloud measured in 1986 on Whiteface Mountain, New York, had a pH of 2.5. There are also seasonal differences in acidic deposition, due to higher sulfate values in summer than winter in the Northeast. Opposite seasonal trends occur in Europe (NAPAP 1987).

Some of the controversy about acidic deposition is which precursor source is the most important, which has a bearing on what kind of control strategy is rational and efficient. One uncertainty centers on what happens in the atmosphere. Some atmospheric scientists contend that sulfur oxides are a sink for oxidants like ozone, which contribute to atmospheric warming, or the greenhouse effect, so that reducing sulfur emissions may increase global warming (MacDonald 1985). Another uncertainty concerns where you look for the impact: in the forest or the lakes, or elsewhere. Sulfate deposition to lakes may be the primary concern; however, hydrogen peroxide and ozone are the more likely pollutants of concern in forests, although we really cannot be certain in either case (NAPAP 1987).

POTENTIAL EFFECTS

"How does acidic deposition affect the environment?" is a question many researchers have asked over the last several decades. Concern has been for the effect on vegetation and water bodies directly, on soil and subsequent indirect effect on vegetation, rivers, and lakes. Other speakers in the workshop will examine the effects on soil and aquatic systems. I will limit my remarks to the effects on forest vegetation.

Some potential effects that have been studied in the lab include the following (Morrison 1984):

- Direct damage to leaf surfaces from the contact of the acidic material.

- Direct damage to reproductive organs, resulting in fewer, weaker seedlings.

- Direct effect of leaching of nutrients from tree crowns, resulting in lower growth or abnormal growth.

Indirect, or non-contact, effects result from harm to other parts of the forests; one example would be microbes in the soil that are important because they decompose organic matter and release nutrients that the trees use.

Another indirect effect is the acidification of soil and subsequent leaching of nutrients, or the increase in amounts of aluminum and other trace elements that are changed into compounds in soil that are harmful to trees or microbes.

EVIDENCE OF DAMAGE

The "best" evidence that acidic deposition harms forests comes from Germany. There are widespread declines of several species, with some common symptoms around the country. Declines are especially severe in high-elevation forests. The Germans call this "Waldsterben," or "forest death." There has been a recent, simultaneous, decline in Norway spruce, European beech, and silver fir (Schutt and Cowling 1985). There is a consensus among European researchers that a triggering, or common stress, factor is at work, and many researchers accepted acidic deposition as the trigger.

The common symptoms of Waldsterben in Germany include growth-decreasing effects of increasing severity until the tree dies; as well as abnormal growth, such as stork's nest in white fir and long shoot development in beech. The impression was given, especially in the popular press, that German forests were dying, with more than 50 percent of the forest area in decline. Actually, the lowest damage category, the largest in size, was what foresters in other countries would regard as normal conditions (Binns 1985).

The common symptoms on conifers include increasing transparency of the crown from moderately damaged to the advanced stages of the disease. The loss of the needles typically is older needles, starting from the inside of the branches outward, from mid-crown upward. Similar effects can be seen in Norway spruce, white fir, and Scots pine (Schutt and Cowling 1985).

Symptoms are found on the fine roots of coniferous and deciduous species as well. Roots of declining white fir and Norway spruce will be knotted, lacking mycorrhizae (Schutt and Cowling 1985). This kind of damage is similar to what can be produced in controlled experiments with high aluminum levels (Stanturf 1984).

Until 1982 in West Germany, all damage was confined to higher-elevation forests (Binns 1985; NAPAP 1987). Lately, foresters have noticed symptoms on trees in valleys. Damage has been equally severe to trees in remote, clean-air areas and the heavily polluted areas of Bavaria, so we can rule out direct sulfur dioxide damage as the cause, and and the precipitation pH is too high for direct rainfall damage.

Soil acidification was first thought to be the mechanism, then regarded as not likely since decline was reported on acidic soils as well as soils developed on limestone with high amounts of basic material. Recent findings, however, implicate nutrient deficiencies as a common soil factor, which may be related to soil acidification and leaching of nutrient cations. This has been termed by some "aluminum-induced calcium deficiency." Heavy metal mobilization is not general enough to account for all forest stands with damage (NAPAP 1987).

Ozone has most recently been implicated, but there aren't enough data to be sure. Certainly, ozone levels are high, and some decline symptoms are similar to what can be produced under experimental conditions (Ashmore et al. 1985).

There are some other interesting mechanisms proposed, such as organic growth factors or hydrogen peroxide causing foliar damage; and ammonia increasing growth into the fall after hardening off should occur, with resultant frost damage. The consensus is that the decline is a combination of all these factors, and other stresses not related to air pollution (NAPAP 1987).

THE NORTH AMERICAN SITUATION

We can ask whether the experience from Europe is relevant to our situation in North America. Species are different, and many European forests are plantations rather than natural forests. Pollutant loadings are higher in Europe than here, and the seasonal patterns of deposition are different. What appear to be the same are some of the decline symptoms, and the occurrence in high-elevation forests such as in red spruce stands above cloud base in the Appalachians.

Forest declines in the northern hemisphere have been numerous (NAPAP 1987). There are declines that are dominated by natural biological or physical factors, such as the declines of ash, beech, birch, and the maples in the U.S. and Canada. There are pollution-related declines, which must be separated into those that have been substantiated as due to pollution, and those which are potentially related. One substantiated decline is to Ponderosa pine in the mountains surrounding the Los Angeles basin in California. Potentially related to acidic deposition is the decline of red spruce at high elevations along the Appalachians (Zedaker et al. 1987).

The significance of stands at high elevations are that they are above the cloud base, where the lowest pH occurs in fog and clouds. In the North, "high elevation" is defined as above 3,282 feet. This includes stands in the Adirondacks, the Green Mountains, and the White Mountains. In the South, "high elevation" is defined as above about 3,938 feet. Red spruce occurs at higher elevation in West Virginia, Virginia, North Carolina, and Tennessee (NAPAP 1987).

Let us first be clear what we mean by a growth decline. A generalized growth curve could be constructed for a single tree or a whole stand where initial rapid growth of seedlings into mature trees results in an increase in biomass. A point of maximum growth is reached with the culmination of current annual increment. The next declining segment of the curve is the predictable decrease in growth as a result of natural aging. A situation where the decline is less than "normal" could be due to thinning and fertilization or maybe just better weather. Another curve could show an accelerated growth decline, such as that which would result from natural or human-caused stress. So relating growth declines to acidic deposition is a two-step process: first you must distinguish an observed decline from expected reductions due to age and stand dynamics; then you have to relate the decline to a causal factor or factors.

The decline of red spruce in the U.S. has been called an acidic deposition effect. Studies of high elevation stands seem to document a decline, especially in older trees, but there is no consensus on the cause. Drought stress, natural stand dynamics of older trees dying out, pests and diseases, and lead accumulation have all been stated as causes (NAPAP 1987). Symptoms also differ between northern and southern stands. In the South, foliar damage symptoms are similar to the European decline symptoms: older needles are affected first, needle loss is from the inside outward, from mid-crown upward. In New England and New York, red spruce dies back from the top down. New needles at branch tips die first (NAPAP 1987).

There has been up to 70 percent decrease in red spruce biomass on Camel's Hump in Vermont, with lesser declines in biomass of white birch and balsam fir (Vogelmann et al. 1985). Decline in red spruce on Whiteface Mountain in New York has been severe also, but is somewhat less impressive when only undisturbed stands are included (Scott et al. 1984). In the southern Appalachian stands, mortality has been less severe but still high and growth declines are apparent in ring width series, even in index series where ring widths are standardized to remove age and site effects (Adams et al. 1985).

Growth declines have been demonstrated as well for low-elevation spruce stands in new England. Some have drawn the obvious comparison to the central European decline chronology, where damage first appeared at high elevation and several years later had spread to lower-elevation forests.

In New England, the declines in low-elevation spruce stands appear to result from natural processes. Jim Hornbeck and others cored over 3,000 red spruce and 1,300 balsam fir from stands across New England and New York. Radial growth was converted to basal area growth and plotted over time. Each point represented an average of over 300 trees. Against this was plotted data taken in 1920 from comparable second growth, even-aged stands in temporary plots, the work of Meyer. Hornbeck and his co-workers found apparent agreement between the two growth curves and concluded that the decrease in basal area growth that started in the 1960s is a natural result of stand structure (Hornbeck et al. 1986).

We may not be able to apply this explanation to the high-elevation forests, as they are of different age, density, and history of disturbance. There is evidence, however, that at least in West Virginia, the high-elevation red spruce stands of today remain after widespread decline in the late 1800s. An old West Virginia experiment station report, published circa 1892, tells of salvage logging in Randolph County, on Cheat Mountain at an elevation of 3,425 feet. The general opinion at the time was the widespread decline resulted from a severe drought in 1882 and 1883. One landowner, a Col. Hutton, observed that trees began dying between about 1880 and 1882, and continued to die for five or six years. Over 300,000 acres were affected, with death most frequently of the largest trees (Annon. 1892).

CONCLUSIONS

Acidic deposition is real; while we don't have data, strong inference of past trends and knowledge of current trends support the conclusion that precipitation has been acidified, and significant dry deposition of acidic material exist, especially over eastern North America.

Sources of the acidic material are known, but their relative importance is uncertain. Also, our limited understanding of atmospheric chemistry suggests an interaction between acidic deposits and global warming. So we are more than a little uncertain as to the best control strategies.

Serious declines of forest species in Europe and North America have occurred, are occurring, and certainly will occur. It is not always easy to separate "normal" declines due to age, stand development, and climate from accelerated declines from biological stresses like disease and insects or physical stress like air pollution. They may be inseparable in any rigorous sense, as endemic regional air pollution stress may predispose affected forests to biological stresses. At any rate, an approach to relating growth declines to any pollution stress requires first that an observed decline be shown to be greater than normal growth reductions as a tree or stand matures, and second that a causal linkage be established between growth reductions and stress factors. Simply noting that growth is reduced, or that old trees die, in an area receiving high levels of acidic deposition does not establish a linkage. As the statisticians admonish, correlation does not prove causation.

The acidic deposition controversy shows to me that we lack an understanding of what constitutes a healthy forest ecosystem adequate to judge when our forests are adversely affected by less than catastrophic stress. Perhaps good baseline data from very long-term experiments would have helped, but we lack those, too. What we can conclude today is that we lack compelling evidence for widespread acidic deposition damage to forest vegetation.

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